



## The extreme flood event of Lago Maggiore in September 1993

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### Abstract

In September 1993, the Valais and Ticino regions of Switzerland were affected by extreme flooding triggered by heavy precipitation. The meteorological situation leading to this event is studied in the Twentieth Century Reanalysis (20CR) data set. A strong cut-off low development is found to be the driving synoptic-scale atmospheric circulation pattern. The agreement with previous studies highlights the applicability of 20CR for extreme event analysis.

### 1. Introduction

The central Alps show large heterogeneity with regard to precipitation due to shielding and slope effects. The southern slopes of the central Alps are particularly prone to episodes of heavy precipitation (Frei and Schaer, 1998). In synergy with hydro-meteorological preconditions such as saturated soils and snow melt, heavy precipitation episodes can lead to flood events (*e.g.*, Stucki et al., 2012). In the Canton of Ticino, the largest flood events occur in the Ticino catchment (including the Lago Maggiore basin), which is characterized by very steep slopes, large elevation differences and by runoff of nearly 1500 mm/a (Spreafico and Weingartner, 2005). Since these floods can cause severe damage, it is relevant to understand the hydrological and atmospheric conditions prior to and during such events.

Heavy precipitation events on the southern slope of the Alps are typically triggered by an upper-level trough that decays into a cut-off low (*e.g.*, Massacand et al., 1998). The upper level trough ensures steady inflow of warm and moist air from the south. The warm air is typically accompanied by a very high snow line (3500 m a.s.l.; Grebner, 1993).

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**Figure 1.** Photo of the Piazza Grande in Locarno on 3 October 1993 (Source: Repubblica e Cantone Ticino).

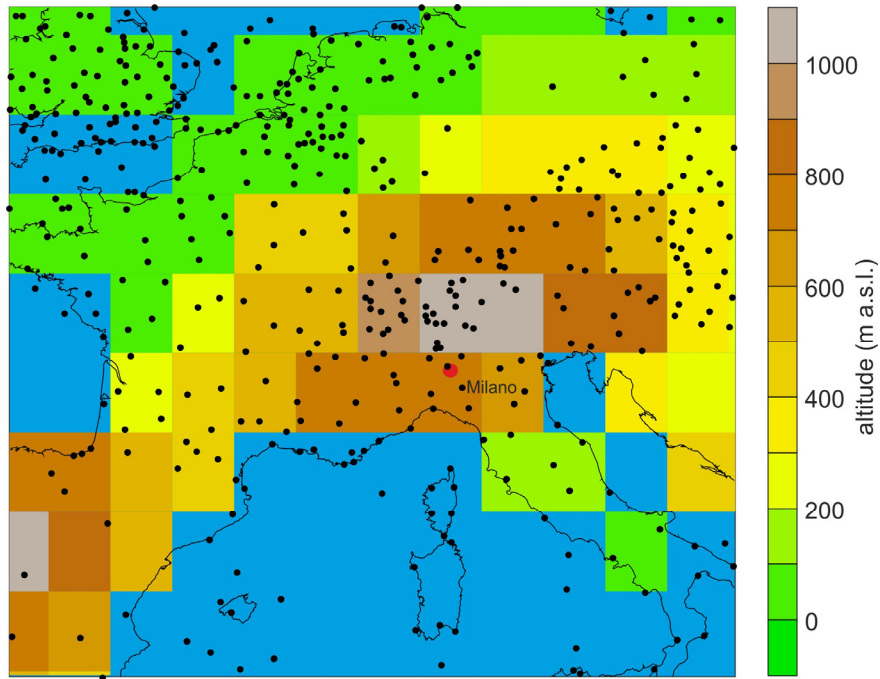
In this paper, we study the flood event of September 1993. The event is known for the flooding and debris flows in Brig/Valais, but also for severe damage in the Lago Maggiore basin (Pfister, 1999). The lake level at Locarno rose 1.16 m per 24 h on 24 September and 2.8 m from 23 to 25 September, and it reached the third-highest water level since 1868 (197.82 m a.s.l.) on 9 October 1993. Figure 1 shows the flooded Piazza Grande in the old town of Locarno on 3 October 1993. The flood event had been the costliest event in the area so far, with estimated losses of 650 Million Swiss Francs (Röthlisberger, 1994).

The event is relatively well studied using traditional data sets (*e.g.*, Grebner, 1993; Landeshydrologie und –geologie, 1994; MeteoSwiss, 1995; Massacand et al., 1998; Buzzi and Foschini, 2000). It therefore serves as an interesting example to test the applicability of another, new data set, namely the Twentieth Century Reanalysis, version 2 (Compo et al., 2011), for the problem of studying heavy precipitation events.

In the following, we present an analysis of the large-scale meteorological situation leading to the extreme flood events of September 1993 in the Valais and the Lago Maggiore basin. Section 2 describes data and methods used. In Section 3, we shortly describe the precipitation and the meteorological development during the extreme event of 22 to 25 September 1993. A discussion is given in Section 4. Conclusions are drawn in Section 5.

## 2. Data and Methods

The analysis considers the Twentieth Century Reanalysis version 2 (20CR), which is a global three-dimensional atmospheric dataset that reaches back to 1871 (Compo et al., 2011). It is based on an assimilation of observed surface or sea-level pressure and on HadISST (Rayner et al., 2003) monthly sea surface temperature and sea ice distributions as boundary conditions for the Global Forecast System atmosphere/land model (NCEP/GFS) at a spatial resolution of



**Figure 2.** Map of the study area displaying the 20CR topography and land-sea mask. Dots indicate surface or sea-level pressure information assimilated into 20CR. Colours indicate the orography in 20CR and the land-sea mask as depicted in the Gaussian grid (192 x 94 cells). For orientation, the location of Milano is also indicated.

T62. Assimilation is performed using an Ensemble Kalman filter, with 56 ensemble members. Here, we use the ensemble mean in the analysis and the figures.

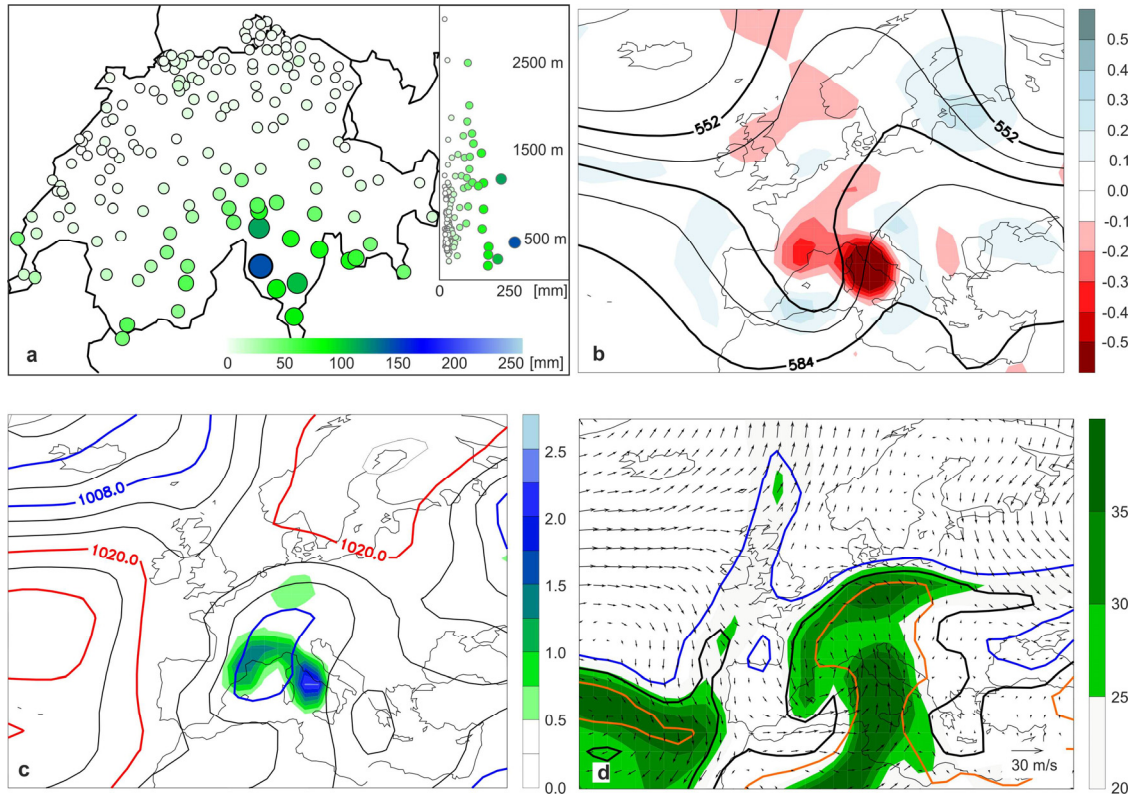
We focus on the 500 hPa geopotential height (GPH) and sea-level pressure (SLP) as an indicator of the general flow structure, 500 hPa vertical velocity ( $\omega$ ) as an indicator for lifting, equivalent potential temperature ( $\theta_e$ ) at 850 hPa to identify air mass boundaries as well as wind at 850 hPa and precipitable water to analyze the moisture flux.

The 20CR data provide information only on the large-scale circulation. The resolution is  $2^\circ$  longitude x  $2^\circ$  latitude or approximately 200 x 200 km, and the orography of the Alps is smoothed substantially. Figure 2 shows the model orography, together with the surface and sea-level pressure data assimilated. As a consequence of the smooth orography, we do not expect very local extremes to be well depicted. Moreover, extremes are further expected to be smoothed because we analyze the mean of 56 realizations. As the data set does not resolve small-scale features in the precipitation field such as those caused by orographic effects, we supplement the data with daily amounts of precipitation from the MeteoSwiss station network.

### 3. Results

#### 3.1. Precipitation distribution

After some days with little to no precipitation in the area, an episode of heavy precipitation on the south side of the Alps started on 22 September 1993. For instance, a precipitation rate of 127 mm within 24 hours was observed at the Airolo station at 1139 m a.s.l., located just south of the Alpine divide. The daily records in the area exceeded 100 mm on 25 September.



**Figure 3.** Precipitation and meteorological fields for 24 September, 1993. (a) Precipitation recorded at Swiss rain gauge stations (the inset shows the precipitation as a function of elevation) in mm/24 h. (b) GPH (black lines) in geopotential decametres and vertical motion ( $\omega$ , in Pa/s, ascent in red, subsidence in steel blue shades) at 500 hPa. (c) SLP (lines, in hPa) and precipitation rate (shaded, in mm/h over 3 h around noon). (d)  $\theta_e$  at 850 hPa (blue, black and yellow lines mark 16, 24, and 32 °C), wind (arrows), and precipitable water (mm, shades). (b) to (d) are from 20CR.

Until 23 September, mainly the western Ticino was affected, and then the precipitation area expanded to the east and north across the Alpine divide. The situation on 24 September is depicted in Figure 3a. The heaviest precipitation occurred in the western Ticino/Domodossola area (145.8 mm at Cevio, 418 m a.s.l.). Precipitation amounts of more than 50 mm were observed from the Alpine divide (Uri, Valais) to Milano (Northern Italy) at all elevations.

Compared to these local observations, the 20CR ensemble mean (Fig. 3b) shows relatively modest precipitation rates, and the main precipitation field is shifted to the western and especially the Maritime Alps on 24 September 1993.

### 3.2. Meteorological situation

By 22 September, a narrow upper-level trough had formed over Brittany upstream of a blocking ridge over southeastern Europe/Russia. The trough produced a meridionally elongated cut-off low, and a surface low developed over the Gulf of Lion, which moved slowly north-eastward over the next three days. The situation on 24 September is depicted in Figure 3. At 850 hPa, the low-level flow steered very moist and warm air from the south towards the Alps, as can be seen in the high values of 850 hPa  $\theta_e$ , wind, and precipitable water (Fig. 3c and d).

Strong uplift is indicated by negative values of  $\omega$  at the 500 hPa level (Fig. 3b) on the eastern side of the cut-off low, *i.e.*, at the southern slope of the Alps. Similar to precipitation, the area of strongest uplift is located over the Tyrrhenian Sea.

#### 4. Discussion

Our analysis shows that prior to the event, a mid-tropospheric trough formed over Brittany and developed into an elongated cut-off low. The cut-off low triggered cyclogenesis over the Gulf of Lion. In fact, this process has been studied by various authors, who specifically addressed the role of the narrow, meridionally aligned trough in the upper troposphere (e.g. Massacand et al., 1998, 2001; Buzzi and Foschini, 2000; Hoinka et al., 2006). In this sense, the flood event of September 1993 is a typical example for the mechanisms responsible for heavy precipitation at the southern slope of the Alps (see also Stucki et al., 2012).

The development of the trough and the cut-off low is relatively well depicted in the 20CR data. However, the mid-tropospheric lifting and the associated precipitation fields are shifted southward and the modelled precipitation rates are far below the observed extreme values. An almost-stationary, deep low over the Balearics/Ligurian Sea was the key element of low-level flow (Grebner, 1993). Mesoscale model simulations point to the central role of convection and illustrate the counterclockwise rotation of the frontal system, suggesting that the regional precipitation occurred in prefrontal circulation on 23 September and was associated with the cold front passage on 24 September (Buzzi and Foschini, 2000).

In summary, the heavy precipitation on the south side of the Alps was likely due to a combination of synoptic and mesoscale forcings. Mid-tropospheric large-scale ascent supported deep convection over an area where abundant low-level moisture transport, convergence and orographic lift occurred. The importance of deep convection is indicated by the absence of an elevation gradient of precipitation (Fig. 3), *i.e.*, heavy precipitation was observed at all elevations.

#### 5. Conclusion

The flood event of September 1993 in Ticino is studied using meteorological data from the Twentieth Century Reanalysis (20CR). The flood was triggered by heavy precipitation and led to one of the highest water levels of Lago Maggiore in the instrumental period. Our findings are in agreement with previous studies (Grebner, 1993; Röthlisberger, 1994; Massacand et al., 1998) in that the event was caused by continuous heavy precipitation induced by a quasi-stationary upper-level trough/cut-off system, warm and humid southerly inflow and high temperatures (with the snow line at 3000 m or even higher), and fast runoff formation on saturated soils. A narrow upper-level trough, from which a cut-off low developed, played an instrumental role in triggering the heavy precipitation event.

Although just constrained by SLP, the Twentieth Century Reanalysis is able to reproduce the synoptic-scale atmospheric features which were essential for this anomalous precipitation event and flooding. However, the intensity of the precipitation event is underestimated in the ensemble mean and the regional-scale precipitation distribution is not well represented in 20CR. This is expected from the low spatial resolution of 2° longitude x 2° latitude and the resulting averaging over a large region and the coarsely resolved topography of the Alps.



## Acknowledgements

20CR data were obtained courtesy of the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at <http://www.esrl.noaa.gov/psd/>. Support for the Twentieth Century Reanalysis Project dataset is provided by the U.S. Department of Energy, Office of Science Innovative and Novel Computational Impact on Theory and Experiment (DOE INCITE) program, and Office of Biological and Environmental Research (BER), and by the National Oceanic and Atmospheric Administration Climate Program Office. Precipitation data were provided by MeteoSwiss. The work was supported by the Swiss National Science Foundation (NCCR Climate, Project PALVAREX III, project “EVALUATE”) and the EU FP7 project ERA-CLIM.

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